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Control of Tomato Leaf Mold in Greenhouses

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This bulletin presents a description of various practices which contribute to the control of Cladosporium leaf mold, a serious foliage disease of tomatoes grown in greenhouses.

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CONTROL OF TOMATO LEAF MOLD IN GREENHOUSES

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INTRODUCTION

Tomato leaf mold is essentially a foliage disease of greenhouse tomatoes. Outdoor tomato plantings become diseased in weather marked by periods of high temperatures and stagnant, moist air, and particularly in locations lacking good air drainage and near greenhouses contaminated with the fungus. The disease is never of general occurrence and usually is of no importance on field tomatoes in Massachusetts.

The disease is epidemic in the greenhouse in September and October on the fall or second planting of the year and before much harvest of fruit. On the spring or first planting of the year the disease often becomes epidemic in June after the last trusses have set fruit but when it is too late for the disease to do much noticeable damage to the yield. The measured loss may, however, be considerable.

The seriousness of the disease in the greenhouse is associated with high temperatures and high relative humidities prevailing during the warm months of the year. These conditions are readily obtained in a confined atmosphere of growing plants. The differences occurring between inside and outside atmospheric conditions during the year have a significant bearing on the development of the disease.

In greenhouse tomato culture in Massachusetts the monthly mean maximum temperatures are usually about 10° to 16° F. higher from May to October inclusive (corresponding approximately to the off-heating season) and usually about 20° to 40° F. higher from November to April inclusive (the heating season), than the corresponding outside monthly mean maximum temperatures. The monthly mean minimum temperatures in the greenhouse from May to October are usually about 2° to 12° F. higher than the corresponding outside monthly mean minimum temperatures. This difference increases to about 40° to 42° F. during December to February inclusive and gradually diminishes again as the season advances. This increase and decrease in the temperature difference as the outside temperatures diverge in the fall from and converge in the spring upon the inside minimum growing temperature of 60° F. significantly influence the humidity of the greenhouse air and the prevalence of the disease. In the period from May to October inclusive, boiler heating is unsteady or lacking; and in May, June, September, and October, practice allows the greenhouse temperatures to drop more or less to 50° F. In the off-heating season the monthly mean maximum relative humidity is 100 percent and the monthly average mean relative humidity is about 78 to 82 percent in contrast to a monthly mean maximum relative humidity of 80 to 94 percent and a monthly average mean relative humidity of 70 to 80 percent in the heating season, the lowest relative humidity coinciding with the coldest months. The seriousness of the disease, therefore, is associated with the off-heating or warmest months of the year when the relative humidity and temperature of the greenhouse air are at their maximum. Since the disease is not of any significance and indeed is usually absent in field plantings in this climate because of the weather peculiar

[1]The writer is gratefully indebted to Dr. W. S. Ritchie and Dr. E. B. Holland of the Department of Chemistry for the chemical analyses reported in Tables 13, 15, 16, and 18, and for chemical interpretations relative to these studies.

to the open, it seems that outside conditions and boiler heat can be advantageously utilized, and in a manner consistent with good growth, in greenhouse management to control the disease, especially when aided by other useful contributory cultural and sanitary measures.

GREENHOUSE PLANTING DISTANCES AND PRUNING

The suppressive effect of light, low relative humidity, and dry foliage conditions on the fungus and infection is recognized. Close planting and abundant plant growth encourage excessive moisture by interfering with the circulation of air. They cause undue shading and poor light. The influence of pruning and adequate spacing on air circulation and moisture removal and the penetration of light can be significant and very useful in contributing to the control of the disease. The lowest leaves of the plants always show the first signs of disease and their early removal is a desirable sanitary practice.

A planting distance of 3 feet by 14 inches in the spring growing season is commonly used in commercial practice. In the fall growing season with light conditions less favorable for plant growth and moisture conditions very favorable for the fungus, wider spacing is essential to the control of the disease. Double rows of single leader plants or single rows of double leader plants are objectionable in the spring growing season unless a generous amount of space is provided between the rows, and they are not recommended for the fall growing season. For double rows of single leader plants a distance of at least 15 inches inside between the rows and 3½ feet outside between the double rows is desirable. If the plants are grown in single rows to two leaders a distance of 4 feet between the rows and 15 to 18 inches between the plants in the rows is desirable. Wider spacing than the foregoing distances would be excessive. Whether a system of double rows of single leader plants or single rows of double leader plants is adopted, light and air conditions about the leaders will be greatly improved by staggering every other leader away from the row. Close planting or crowding does not increase yield per square foot of space. Sufficient spacing to permit light and air currents is also essential to pollination and ripening. On the other hand, the cost of excessive spacing is prohibitive. It also encourages the curling of the leaves exposed to the bright rays of the sun for long periods during the day. This unhealthy condition has now and then aroused the fear and curiosity of the grower.

After the plants have made a strong growth and before they have grown to 2 feet, the lowermost leaves can be removed. If the growth above is dense and rank, an occasional leaf on the stem can be removed. When the fruit on the lower trusses has reached full size the plants will stand more pruning below the fruit. The practice of removing the leaves below the trusses that are ripening off is desirable. (Figs. 1 and 2.) If the lower leaves are infected with leaf mold, drastic bottom pruning can aid in retarding the progress of the disease. These bottom leaves at any rate eventually turn yellow and become of no use to the plant, and might as well be dispensed with earlier. Stone (49, 50) regarded the lack of light as favorable to disease attacks in the greenhouse and advocated the removal of foliage to improve light conditions. Dyke (14) advocated the removal of foliage to improve light and undercurrents of air.

Excessive foliage pruning can be harmful to the swelling of the fruit and to good yields. Therefore good judgment is needed in providing the right balance of foliage to fruit. The heavy, free-setting varieties require vigorous, healthy foliage to insure good-sized tomatoes, so that with these types pruning must be practiced with discretion.

WATERING PRACTICES

The method of watering tomatoes under glass has a bearing on the conditions which contribute to the prevalence of leaf mold. The time of day and the character of the weather prevailing when water is applied are also very important.

Sprinkler systems wet the foliage and produce moisture conditions on the leaves conducive to the best general development of the disease. The open hose method is most generally used, but it causes the water striking the ground to splash on the foliage and offers the temptation of watering from the walks. Simple and inexpensive watering nozzles or shovels can be attached to the hose to confine the water to the bottom of the plants and these implements are used by many growers who have recognized the importance of keeping the foliage dry.

Small (42, 45) demonstrated with a few plants that the wetting of the foliage had no appreciable effect on the prevalence of tomato leaf mold. Newhall (29) asserted that a planting carefully bottom-watered is as subject to attack as one sprinkled overhead. In the writer's experiments, however, which simulated commercial greenhouse conditions, evidence of the effect of wetting the foliage on the incidence of the disease was clearly demonstrated. Two greenhouses were each divided into two equal areas. In one area the watering was done with a sprinkler system and the foliage was thoroughly wetted during each watering. The watering was done in the morning and occasionally in the afternoon. In the other area the plants were bottom-watered with a watering shovel. Leaflets from the prunings during the growing season were counted for a tabulation of the amount of infection. There were totals of 26.2 and 13.8 percent more infected leaflets in those areas where the plants were sprinkled (Table 1). The different disease conditions associated with the two different methods of watering are more clearly shown in Figure 3. These differences, while not significant under the two sets of conditions in the same greenhouse, would have been much greater if each treatment had been made in a separate greenhouse, because of attendant differences in the humidity of the air about the foliage.

TABLE 1.—COMPARISON OF OVERHEAD AND BOTTOM WATERING IN RELATION TO THE PREVALENCE OF TOMATO LEAF MOLD

Fall Cropping Season 1931.

Date of Foliage Counts	Percentage of Diseased Leaflets			
	Overhead Watering		Bottom Watering	
	House No. 5	House No. 7	House No. 5	House No. 7
October 29, 1931	85.7	85.9	78.2	77.1
December 2, 1931	96.3	85.4	75.3	66.7
January 4, 1932	100.0	100.0	80.8	94.6
January 13, 1932	100.0	100.0	47.3	85.3
Total	95.2	92.7	69.0	78.9

The wetting of the foliage contributes to the development of the disease especially if the watering is done late in the day. The experiment also showed clearly the suppressive effect on growth of sprinkling the foliage with cold water.

Impressive instances of the association of epidemics of late blight rot on tomato due to *Phytophthora infestans* (Mont.) De By., and timber rot on cucumber due to *Sclerotinia libertiana* Fckl. with sprinkler watering systems in greenhouses have also been observed. The practice is to be condemned. It offers none but a labor-saving advantage over the slower method of bottom-watering and truly is an example of false economy.

In contrast to overhead irrigation, the watering of the beds through lines of buried tile has been recommended (13, 16, 23, 34). Most greenhouse ranges in Massachusetts devoted to cucumber and tomato culture are underlaid with tile pipes for steam sterilizing which might be adapted for irrigation purposes. Subterrean watering, according to reports, exerts little if any influence on the humidity of the greenhouse air and the surface soil remains dry. This is an important factor in dealing with the disease. Ball (7) invited attention to subterranean watering through tile lines in sweet pea culture and the merit of the idea in controlling foliage diseases. Good control of tomato leaf mold has been reported where the tomatoes are grown in terraces or ridges and the water applied to intervening grooves or furrows (34, 47). In this manner only a small area of the ground is wetted.

Watering should be done on bright days when the houses can be aerated with drier outside air, although in times of prolonged dull or wet weather this rule cannot always be followed. The practice of watering in the morning on bright days makes it easier to control damp conditions at night with heat and ventilation. The greenhouse air at night is more apt to become saturated with moisture and the plants covered with "sweat" if the watering is done late in the day. Mulches of straw or manure on the beds absorb and hold water. Their use emphasizes even more the importance of morning watering and ventilation.

Excessive applications of water and afternoon watering on warm bright days cause the release of water from the leaves and stems, especially if the air in the night following is cool and moist (Fig. 4). Transpiration is suddenly checked while the absorption of water through the roots continues. The exudation of water or guttation creates moisture conditions on the foliage favorable for disease. These drops or beads of water become larger and finally run or drop off the plants. If the watering is moderate in amount and is done in the morning in bright weather and if ventilation is continued at night, guttation can be avoided.

Disregard of these simple rules governing the watering of greenhouse tomatoes can be an important factor contributing to the incidence and progress of tomato leaf mold.

TEMPERATURE AND HUMIDITY CONSIDERATIONS

The management of the greenhouse air to prevent atmospheric conditions favorable to the prevalence of tomato leaf mold is by no means simple. It may contribute to the success of other worthy control measures, or it may undo all of the good accruing from them.

Small (42, 45) emphasized the importance of keeping the relative humidity of the greenhouse air below 75 percent, but this is impossible in greenhouses of any design in Massachusetts. Rippel (40) found that a relative humidity below 85 per cent for 18 to 20 hours each day is not impossible in greenhouses in Germany and this, according to his studies, is necessary to prevent infection. Abnormal atmospheres in the greenhouse are the result of inefficient ventilating and inadequate ventilating area. Both, therefore, are vitally concerned in the problem of controlling tomato leaf mold.

Spore germination occurs in relative humidities above 95 percent and is best at 100 percent or air saturation and in water; and these conditions often occur on the leaf surface and in the immediate atmosphere of the foliage when lower relative humidities exist in the open greenhouse atmosphere. The more humid conditions on the leaf are the result of transpiration and guttation from the foliage and moisture condensation (dew) from the air. A temperature range of 75° to 80° F. is optimum for spore germination and infection, and it is also about the ideal day temperature range for growing tomatoes under glass.

Air circulation is very important in the correction of excessive temperature and moisture conditions. If the ventilators admit insufficient air, opening of doors and construction of additional ventilators in stagnant corners and in the ends of the greenhouse are desirable. Ventilation must be increased with increased heat from the sun. Late in the spring the maximum amount of ventilation may be provided day and night. At this season and in the early fall, when the outside temperatures on occasional nights drop to 50° F., a minimum heating temperature of 60° to 65° F. and ventilation seems best and some ventilation may be necessary from both the sides and the spans of the greenhouse. The ventilators should be lowered but not closed at sundown after the heat is in the pipes. This practice will prevent a sudden rise in the relative humidity of the air.

The appearance of dew or "sweat" on the plants in the morning is rather common in the off-heating season. This happens when the greenhouse is closed at night and the warm confined air is gradually cooled, and can be avoided by ventilation or, if there is a considerable temperature decline, by heat and ventilation. In the fall an inside minimum temperature of 60° to 65° F. with ventilation is often definitely necessary to prevent high relative humidities. This can be appreciated by a study of hygrothermographic records for August, September, and other off-heating periods, of which Figure 5 is typical. The records show that moisture saturation and minimum temperatures of 55° to 60° F. occur at night and high temperatures and low relative humidity in the daytime. The effect of heating on the relative humidity of the air at night is quite insignificant at this season because of the very narrow difference existing at night between the inside and outside temperatures unless the temperatures are raised above 60° F. When the outside night temperatures drop to 50° F. and below, as they do in October and later months, the effect of heat or an inside minimum temperature of 60° F. on lowering the humidity of the air may be considerable, as is indicated by Figure 5B.

In the morning a gradual warming of the greenhouse air above the prevailing night temperature is desirable. This is accomplished by gradually increasing the ventilation as the sun increases in power. In constrast, a sudden cooling of the air at this time may cause a heavy deposit of dew which may remain for some time even after the temperature rises.

Wilson and Alexander (55) and Alexander (5) reported less leaf mold in Ohio greenhouses when heating with ventilation was practiced after June 25. Alexander implied the need of heat as late in the summer as tomatoes are picked and as early as September 1 in the fall season. Walker and Sumner (53) reported less leaf mold in Wisconsin greenhouses when heating began in August. Heating up to late June and as early as the first of September is uncommon in Massachusetts, but where it is practiced, development of the disease is delayed. With coal at nearly $7 per ton delivered, and the average price of tomatoes much less than in pre-depression years, late and early heating obviously absorbs a good share of the profits; and therefore, it has not become a generally accepted practice in Massachusetts.

In spite of diligent management the amount of control of the disease can be entirely out of proportion to the added effort and costs, especially when other contributory control measures are disregarded. The sometimes epidemic occurrence of the disease where late and early heating are practiced is evidence of this fact. Once the disease becomes general on the lower leaves early in the growing period, attempts to check it with heat and ventilation are usually ineffective. For delaying the appearance of the disease or retarding the progress of infection, the practice of ventilating freely from May to October, day and night, and using heat to maintain minimum temperatures between 60° and 65° F. would seem to be ideal. These minimum temperatures are also necessary to promote the steady ripening of the fruit.

EXPERIMENTS IN CONTROL

Hand Management and Minimum Temperature Control

The foregoing information relative to culture and house management was the basis of control demonstrations carried on for several seasons at the Waltham Field Station. Practices recognized as unfavorable to the disease were compared with practices more or less inconsistent with good management and culture. The growing areas were 32 x 32 feet, in different sections of the same greenhouse and separated from each other by glass partitions. The conditions were like those in two adjacent commercial greenhouses except that the temperatures were regulated by thermostats and not by hand-controlled valves. Under poor management, warm, stagnant, moist atmospheres were encouraged by neglect of ventilation and proper methods of watering. Where good management was practiced, efforts were made to keep the relative humidity of the greenhouse air as low as possible with a minimum temperature bordering 60° F., and not to permit temperatures above 70° F. from late April to mid-November without some ventilation. Efforts to prevent high relative humidities at night without heat were not generally successful in the early fall and at other critical times, as is evident from a study of the hygrothermographic records in the greenhouse for September, October, and November, as shown in Figure 5A. A comparison of Figures 5A and 5B reveals the influence of boiler heat on relative humidity, but this is usually of small significance in the months from September to November when the outside and inside minimum temperatures parallel each other closely. As the outside temperatures become colder and diverge further from the inside minimum temperature of 60° F., the influence of boiler heat on the relative humidity becomes more marked (Fig. 5B) and the development of the disease is retarded.

The effect of the two methods of management on the control of the disease was determined by a tabulation of healthy and infected leaflets at each pruning. In the fall growing season (1926) 30 percent of the leaflets were infected with leaf mold under poor management and 33 percent under good management (Table 2). The disease was not important enough to influence the yield. In the spring cropping season (1927) 76 percent of the leaflets showed leaf mold under poor management and 19 percent under good management (Table 3). In this season the average yield per plant under good management was 9.24 pounds, of which 8.64 pounds were classed as first grade fruit, in comparison with 8.67 pounds obtained under poor management, of which 7.85 pounds were fruit of first grade. In the fall cropping season (1927) there was no contrast in the amount of disease. It was bad in both houses and there was no heat to permit good management during the early critical period, because of the installation of new boilers.

TABLE 2.—CONTROL OF TOMATO LEAF MOLD BY GREENHOUSE MANAGEMENT
Fall Cropping Season 1926.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	With Poor Management	With Good Management
September 20, 1926	35	9
October 1, 1926	6	2
October 6, 1926	8	23
December 20, 1926	35	75
January 11, 1927	84	56
January 29, 1927	27	28
Total	30	33

TABLE 3.—CONTROL OF TOMATO LEAF MOLD BY GREENHOUSE MANAGEMENT
Spring Cropping Season 1927.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	With Poor Management	With Good Management
June 16, 1927	56	0.1
July 12, 1927	98	14.0
July 31, 1927	100	32.0
Total	76	19.0

TABLE 4.—CONTROL OF TOMATO LEAF MOLD BY GREENHOUSE MANAGEMENT
Spring Cropping Season 1928.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	With Poor Management	With Good Management
April 4, 1928	0.0	0.0
April 16, 1928	5.06	0.16
May 7, 1928	34.69	0.55
May 18, 1928	75.0	1.02
June 12, 1928	100.0	3.00
June 28, 1928	100.0	3.56
July 17, 1928	100.0	6.65
Total	45.09	2.08

TABLE 5.—RELATION OF LEAF-MOLD CONTROL TO YIELD AND VALUE OF TOMATOES

Spring Cropping Season 1928.

	With Poor Management	With Good Management
Average yield per plant:		
Firsts.....pounds	5.17	7.99
Seconds.....pounds	2.55	2.56
Total.....pounds	7.72	10.55
Average value per plant:		
Firsts.....	$1.53	$2.36
Seconds.....	.30	.32
Total.....	1.87	2.68
On ¼-acre basis:		
Total yield.....pounds	15,980.4	21,838.5
Total value.....	$3,870.90	$5,547.60

In the spring growing season (1928), 45 percent of the leaflets were infected with leaf mold under poor management and only 2 percent under good management (Table 4). This control meant a significant average increase per plant of 2.83 pounds and 81 cents, or 5,858 pounds and $1,677 on a quarter-acre basis (Table 5).

In the fall season (1928) 85.6 percent of the leaflets showed leaf mold under poor management and 14.5 percent under good management (Table 6); but the difference in yield was only .79 pounds and 20 cents per plant, or 1,635 pounds and $414 on a quarter-acre basis (Table 7). The small difference in yield with a significant contrast in disease conditions showed that there were other factors limiting yield. It is also apparent that considerable foliage loss from the disease is necessary before there is any loss in yield. While the value from good management practices alone was not always striking, nevertheless in general the results show justification for the effort.

TABLE 6.—CONTROL OF TOMATO LEAF MOLD BY GREENHOUSE MANAGEMENT

Fall Cropping Season 1928.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	With Poor Management	With Good Management
September 11, 1928.....	0.0	0.0
September 25, 1928.....	4.1	8.1
October 26, 1928.....	90.6	36.8
November 22, 1928.....	100.0	22.5
December 22, 1928.....	100.0	10.5
January 10, 1929.....	100.0	8.1
January 30, 1929.....	100.0	13.3
Total.....	85.6	14.5

TABLE 7.—RELATION OF LEAF-MOLD CONTROL TO YIELD AND VALUE OF TOMATOES

Fall Cropping Season 1928.

	With Poor Management	With Good Management
Average yield per plant:		
Firsts.....pounds	2.79	3.59
Seconds.....pounds	1.56	1.55
Total.....pounds	4.35	5.14
Average value per plant:		
Firsts.....	$0.66	$0.86
Seconds.....	.18	.18
Total.....	.84	1.04
On ¼-acre basis:		
Total yield.....pounds	9,004.5	10,639.8
Total value.....	$1,738.80	$2,152.80

Forced Air Ventilation and Humidity Control

By the simple method of introducing outside air over a heater, Stair et al. (48) completely prevented tomato leaf mold from developing on plants in the hotbed. Wilson (56) noted that with forced air no periods occurred up to May 14 when the relative humidity was 86 percent for 10 hours or more, while naturally ventilated houses showed at least 35 such periods. For the first monthly periods in the spring, the average relative humidity in a naturally ventilated house was 77.7, 77.8, and 82.5 percent in contrast to 61.5, 67.5, and 72.1 percent in a forced-air-ventilated house. The possibility of controlling the disease by combining forced air with natural ventilation was suggested from these readings. The admission of the inconsistency and unreliability of hand control of ventilation and heating in commercial practice stimulated the commercialization of costly automatic systems of greenhouse air conditioning. The Zephyrator (1, 2, 3, 27, 28, 29), reported to have been installed in several ranges in Ohio, relied upon an electrically driven centrifugal blower to force air through underground pipes and overhead ducts into the greenhouse, the purpose being to increase the evaporating power of the air by stirring it. Evaporation was doubled without appreciable draft (Newhall 29) when air was stirred at the rate of 44 feet per minute and in a range of 1½ acres the air was changed theoretically in 22 to 30 minutes. Parker (32) asserted that air must move at the rate of 2 feet per second to prevent atmospheric stagnation and at this velocity there is a complete change of air without drafts. Newhall (30) described an installation in which the blower is placed in front of a series of radiators which may be fed with either steam or cold water so that the greenhouse air may be warmed or cooled.

Another system (4) first compressed the air to a fraction of its volume then introduced it into the greenhouse through a series of perforated pipes, similar to an overhead sprinkler system which could be adjusted for any desired angle and volume. The compression of the air greatly increased its capacity to absorb water.

Guba (18) described a system of relative humidity control and forced ventilation relying on the variation of the greenhouse temperatures between a fixed minimum and maximum and by the starting and stopping of exhaust fans. This is brought about by a hygrostat which shifts from a low to a high thermostat and which may be set at any desired temperature range. By increasing the temperature when the relative humidity rises, the humidity will tend to be lowered in a definite ratio for each degree rise in temperature. The starting of exhaust fans simultaneously with the introduction of pipe heat stirs the air and causes the infiltration of outside cooler air. This system insures considerable accuracy since it relies upon the sensitivity of thermostats and hygrostats. There is no draft of air or inside construction to make shadows or take up growing space as in the Ohio installations. This system of humidity control and forced ventilation was compared with a fixed thermostatic minimum temperature control and hand ventilation in two separates houses designated A and B.

The minimum temperature in greenhouse B was adjusted for 60° F. (temperature control) and Figure 5B shows the influence of such a prevailing minimum temperature upon the course of the relative humidity of the greenhouse air in the colder months of the year. In greenhouse A, air control instruments were gauged for relative humidities below 85 percent (humidity control), which was not always possible within a temperature range of 60° to 75° F., representing the extreme adjustment for the low and high thermostats. This was especially true during September, October, and critical periods in November. With the advance of the season and the decline of the outside mean minimum temperature, the maintenance of relative humidity below 80 percent within a fluctuating temperature range of 60° to 70° F. was more readily accomplished. In April to June, conditions again are like those in the early autumn months.

Less attention to ventilation was necessary in greenhouse A provided with air-conditioning equipment than in greenhouse B with thermostatic minimum temperature control only. In the former, the ventilators were opened when the temperature reached 72° to 75° F.; in the latter, ventilation was much more freely applied, but the conditions were not as accurately controlled.

The results under the two conditions of air control in the fall of 1929 (Table 8) showed a difference of 17.6 in percentage of infected leaflets, the greater amount

TABLE 8.—RELATION OF AUTOMATIC HUMIDITY REGULATION AND AUTOMATIC TEMPERATURE REGULATION TO THE CONTROL OF TOMATO LEAF MOLD

Fall Cropping Season 1929.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	House A Humidity Control	House B Temperature Control
August 21, 1929	0.0	0.0
September 24, 1929	15.4	16.8
October 31, 1929	84.4	93.1
November 27, 1929	49.5	99.0
January 2, 1930	17.4	57.9
January 15, 1930	20.1	23.4
Total	33.2	50.8

of disease being present where humidity conditions were rather indifferently regulated and where the minimum temperature bordered 60° F.

The same comparisons were made in the fall cropping season of 1930. There were 28.7 percent more infected leaflets in greenhouse B where a fixed minimum temperature of 60° F. maintained only a limited control of the relative humidity than in greenhouse A where a fluctuating automatically controlled temperature and forced ventilation operated fairly well to keep the relative humidity under 85 percent (Table 9).

TABLE 9.—RELATION OF AUTOMATIC HUMIDITY REGULATION AND AUTOMATIC TEMPERATURE REGULATION TO THE CONTROL OF TOMATO LEAF MOLD

Fall Cropping Season 1930.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	House A Humidity Control	House B Temperature Control
October 17, 1930	19.7	21.9
November 21, 1930	25.4	41.2
December 26, 1930	18.2	35.7
January 26, 1931	10.3	63.3
Total	18.2	46.9

The average yield in pounds per plant in each greenhouse was:

Grade of Tomatoes	Greenhouse A	Greenhouse B
No. 1 ..... pounds	2.32	2.9
No. 2 ..... pounds	1.00	1.3
No. 3 ..... pounds	.37	.5
Total	3.69	4.7

The higher yield did not coincide with better control of the disease, which suggests the operation of other limiting factors. Obviously, the fuel cost of regulating the conditions in greenhouse A was greater than in greenhouse B.

Further comparisons were made in the spring cropping season of 1931. The disease was equally bad in both greenhouses. After May 15 all the ventilators were kept open day and night; nevertheless, the disease, which had already appeared, eventually spread to all of the foliage. The yield and quality of the tomatoes did not appear to be seriously affected. Where the humidity was kept fairly well below 85 percent within a temperature range of 60° to 75° F., the yields averaged 10.28 pounds per plant, of which 7.35 pounds were of first grade, in contrast to a total of 11.92 pounds of which 8.63 pounds were of first grade, under a minimum temperature of 60° F. and natural ventilation. The yields were considered exceptionally good, but relative humidity below 85 percent with temperatures between 60° and 75° F. again showed an adverse influence on yield.

A further comparison of the two sets of conditions was made in the fall of 1931. A difference of only 10.1 in percentage of infected leaflets could be shown (Table 10) in favor of automatic humidity control and forced air.

TABLE 10.—RELATION OF AUTOMATIC HUMIDITY REGULATION AND AUTOMATIC TEMPERATURE REGULATION TO THE CONTROL OF TOMATO LEAF MOLD

Fall Cropping Season 1931.

Date of Foliage Counts	Percentage of Diseased Leaflets	
	House A Humidity Control	House B Temperature Control
October 29, 1931	78.2	77.1
December 2, 1931	75.4	66.7
January 4, 1932	80.8	94.6
January 13, 1932	47.0	85.3
Total	69.0	78.9

In general, the benefit from control measures in these experiments was too insignificant to justify the installation of costly air-conditioning apparatus. The conditions imposed always gave a lower yield. The commercialization of greenhouse air control systems seems to have been too sudden and speculative. Installations involving the forced introduction of outside air and its distribution throughout the growing area through a piping system proved a fallacy. The conveniences of minimum thermostatic temperature control over hand-valve control in greenhouse heating are recognized and several such installations are in use in Massachusetts. The cost of further controlled air conditioning is at present prohibitive and unjustified in commercial practice.

GREENHOUSE DESIGN AND LOCATION

Greenhouse design and location are closely bound up with the problem of disease control. Both govern the means for providing adequate ventilation and air circulation. It has been noted in Ohio (5, 55) that north and south houses with ridge-hinged ventilation have less leaf mold. Multiple houses in a continuous series are objectionable. This type of range is considered more desirable from the viewpoint of ventilation if built in sections of three houses each with side ventilators and the sections connected by a covered alley (5). Judging from experience in Massachusetts, single houses without the connecting covered alley are more acceptable (Fig. 6 A, B). The alley does not permit good air movement about each individual house.

The need for adequate ventilating area in greenhouse design is generally recognized (33, 47). The modern high-ridged, even-span-roofed house all of glass with continuous ventilation on sides, ends, and spans offers a remarkable contrast to the low-span-roofed house with its row of single-pane ridge-hinged ventilators and its back or north side of wood. The earliest construction showed a strong disregard for light and normal atmospheres (Fig. 6 C, D). It has been stated that the best type of greenhouse for tomato culture is one which permits the removal of the greenhouse roof in the summer (15). The improvement in the provision for light and air shown in the evolution of greenhouse design suggests an approach to this end (Fig. 7 A). The inadequacy of ventilating area is still an evil of much of the recent greenhouse construction for tomato culture, and reveals the desira-

bility of closer cooperation between plant pathologists and greenhouse construction companies. There would seem to be no justification in these times for construction with inadequate ventilating area, particularly for tomato culture.

Proper elevation and exposure contribute to successful ventilation. Situations sheltered by trees and shrubs and buildings, or by surrounding elevations of land are objectionable. The planting of trees and shrubs close to the greenhouse for landscape effect is also objectionable. These conditions obstruct light and air and tend to offset the advantages which desirable greenhouse design can contribute toward efforts to control disease (Fig. 7 B, C).

PROTECTION WITH FUNGICIDES

Ordinary preparations of sulfur and copper are of little if any value in controlling tomato leaf mold in the greenhouse (17). The vaporization of sulfur combined with sound cultural and management practices is considered the best method of control (8, 17). The merit of vaporized sulfur has been substantiated by scientific reports and growers' experiences. Temperatures around 70° F. combined with bright sun contribute to the volatilization and toxicity of vaporized sulfur. The treatments should begin in April before the disease appears and be continued at about 10-day intervals until the latter part of June. For the fall planting the treatments should be given before the plants are set out and be repeated at 7 to 10 day intervals until early November. The rate of application cannot be computed in any definite ratio but must be judged by the density of the vapors in the greenhouse air. Excessive charges are not injurious except that they are apt to produce a perceptible residue on the fruit which is difficult to remove.

In practice there has been an evolution of devices for generating and applying vaporized sulfur from a simple assemblage of stove and dish to apparatus of more practical and safer operation attached to the exhaust of an automobile engine and capable of charging large greenhouses in a short space of time.

The sulfuring of the hot steam pipes is not comparable in substance or effect to the superheating and vaporization of sulfur over a heating unit. Sulfur is not vaporized until it reaches its melting point and this requires a steam boiler pressure of around 20 pounds. The usual steam-pipe temperatures merely warm the sulfur and cause it to fume, this being identical with the fuming of the sulfur deposit on the leaf surface under conditions of sunlight and warm house temperatures. Even with a pipe temperature high enough to melt the sulfur, only a small amount is vaporized and most of it runs off and is lost. The practice requires considerable nightly confinement of the greenhouse air and this encourages the progress of the disease. Moreover, protection is most necessary during the off-heating season when ideal conditions for the disease exist. It is much more desirable to use a special portable apparatus for vaporizing sulfur which can be operated independently of the heating system.

Bewley and Orchard (9, 10) successfully controlled tomato leaf mold with a spray consisting of 1/8 ounce of salicylanilide paste (Shirlan H. B.[2]) and ¼ ounce of sulfonated oil spreader (Agral 1[2]) or 1/8 ounce Agral N[2] (36) in one gallon of water. The merit of the spray for this purpose has been generally confirmed (6, 11, 17, 22, 47). The spray does not leave a residue but it cannot safely be used when oil emulsion is used for red spider mite unless 10 days elapse between the two applications. Copper oxychloride suspension (17 percent copper) has also been reported as being effective, but marks the fruit badly. Petroleum oil

[2]Manufactured by the Imperial Chemical Industries, Ltd., Millbank, London, England.

emulsion and ½ fluid ounce of copper oxychloride per gallon are compatible and nonstaining and are recommended in England when both red spider and leaf mold are present (31, 36).

Rippel (38, 39) asserted that the spores of the fungus possess extraordinary resistance to the action of chemicals and require concentrations in excess of the tolerance of the host to obtain control of the disease. It is asserted that a large portion of the soluble poison is absorbed by the thick wall of the spore leaving none to affect the plasm. Guba (17) demonstrated the toxicity of several chemicals to the spores of the tomato leaf mold fungus and indicated the limitations to their merit in greenhouse culture. The practical difficulty of obtaining adequate protection of the lower surfaces of the leaves where infection occurs and the inertness to the fungus of dry chemical residues on the leaves under conditions which otherwise favor spore germination are offered as fundamental reasons for the inability to control the disease with ordinary spraying and dusting materials in greenhouse culture. The necessity of frequent treatments during the critical season and of using fungicides which are both inert to the plant and nonstaining also impose serious limitations to the use of spraying and dusting materials for combating the disease. Many reports show the value of Bordeaux (17) under field growing conditions. The assertion that effective fungicides for controlling leaf mold are lacking is inconsistent with the evidence (6, 9, 10, 11, 17, 19, 24, 41, 46, 47).

ERADICATION OF THE FUNGUS BETWEEN PLANTINGS

The disinfestation of the greenhouse interior to destroy fungous and insect pests existing outside of the soil is an important sanitary practice which obviously should contribute to the control of tomato leaf mold during the succeeding planting. Some disinfestation of the greenhouse interior after cleaning out the vines may be accomplished by treating the soil with chemicals and confining the gases for two or three days after the soil treatment. However, the destruction of pests before cleaning out the finished vines which harbor them is preferable to prevent a reinfestation from the discarded plant material outside. Several chemicals have been used for this purpose but burning sulfur fumigation has received most recognition because it is economical, practical, and lethal to both insects and fungi.

Figure 1. A planting of tomatoes in October pruned to admit light and undercurrents of air.

Figure 2. A planting of tomatoes in July showing the ultimate condition of the plants as the result of the progressive pruning of the foliage below the trusses of matured and harvested fruit. Pruning aids in the eradication of leaf mold and the circulation of air necessary to control relative humidity.

Figure 3. Comparison of overhead and bottom watering in relation to the prevalence of tomato leaf mold. Irrigation pipe and more severely diseased foliage on the left, the result of overhead watering.

Figure 4. Guttation and dew on the foliage are favorable to tomato leaf mold.

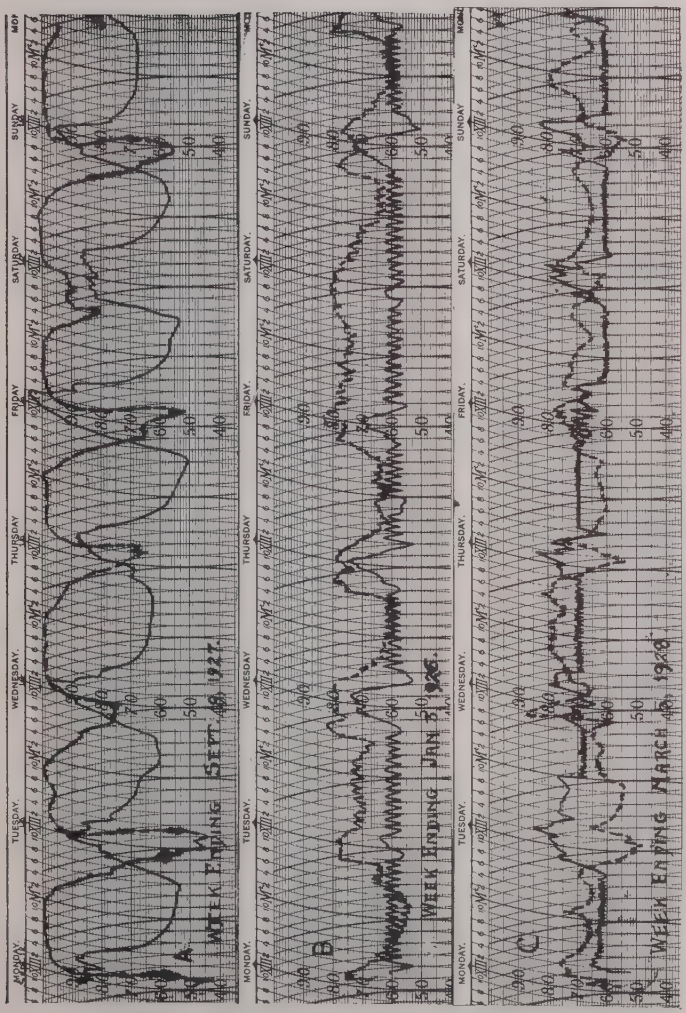

Figure 5. Hygrothermographic records in the greenhouse in tomato culture, showing (A) course of relative humidity and temperature typical of greenhouse atmospheres during the off-heating season; (B) in contrast, the influence of a minimum mean growing temperature of 60° F. on the relative humidity of the greenhouse air; and (C) course of temperature automatically fluctuated between extremes of 60° and 75° F. to maintain relative humidity values below 85 percent. (The solid line represents temperature; the broken line, relative humidity.)

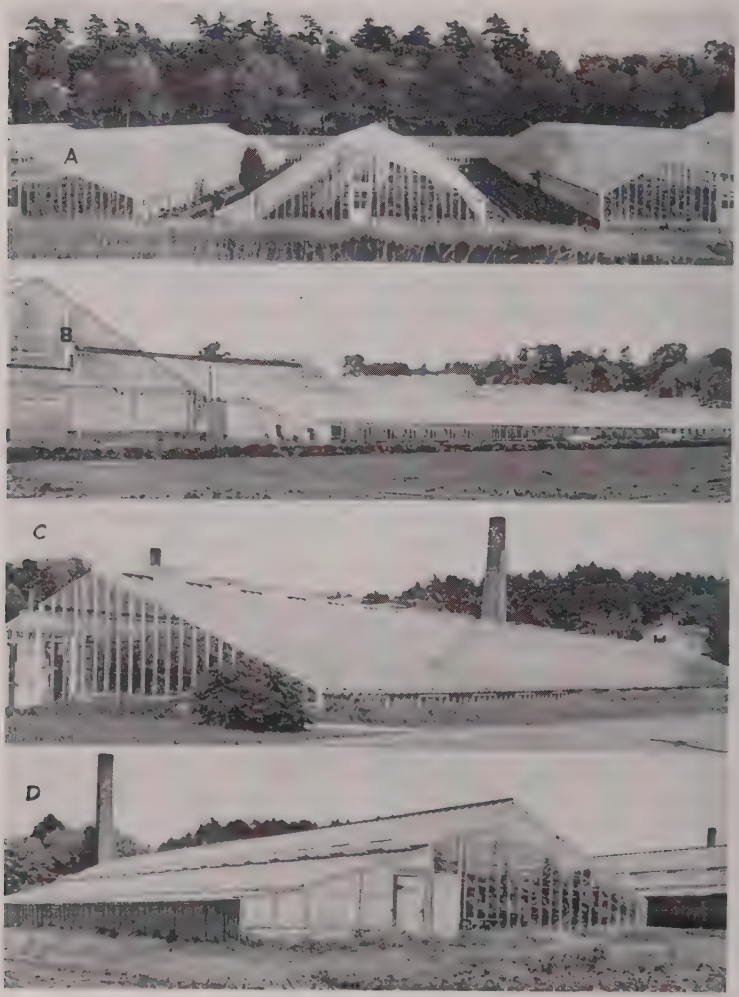

Figure 6. A, B. Greenhouse range showing obstruction to air circulation about the ends of individual houses by a connecting lean-to house. C, D. Low lean-to houses showing a lack of regard for light and ventilating area which makes proper air control very difficult.

Figure 7. A. One of a series of disconnected greenhouses embodying a significant regard for adequate ventilating area, light, and air circulation about each house for controlling tomato leaf mold. All sides and spans are provided with ventilators. B, C. Greenhouse ranges badly situated with respect to exposure to sunlight and atmospheric drainage.

Fumigation with Burning Sulfur

Past recommendations show a lack of uniformity in dosage recommendations for burning sulfur between crops in greenhouses. Most of the recommendations are based on the dosage necessary to accomplish destruction of the red spider mite (Table 11).

TABLE 11.—QUANTITY OF SULFUR TO 1,000 CUBIC FEET RECOMMENDED FOR BURNING IN THE DISINFESTATION OF GREENHOUSES

Authority	Quantity	Period	Remarks
Makemson (26)	5 pounds	24 hours	
Williams (54)	2 pounds		1 percent concentration of SO_2
Small (44, 46)	1 pound		Distributed in 5 heaps
Van der Meer (52)	10 ounces	2 hours	In commercial practice
Van der Meer (52)	2½ ounces	½ hour	In laboratory chamber
Read (36)	1 pound		
Haseman and Jones (20)	30 pounds		For greenhouse pests in general
Compton (12)	3-5 pounds		For greenhouse insects

Small (43, 44, 46) noted that several heaps of burning sulfur gave better results than the same quantity of sulfur in one heap, and that rapid generation of the gas was essential to an effective destruction of the spores of the tomato leaf mold fungus. Judging from recommendations in popular articles, the ratio of 1 pound of sulfur to 1,000 cubic feet of greenhouse space has received most general acceptance. It is generally conceded that, even at this dosage, some eggs and mites survive. This fact has led to the practice of burning even greater amounts of sulfur to 1,000 cubic feet.

The burning of excessive quantities of sulfur in greenhouses between plantings is harmful to iron frames and piping, wires, metal gutters, and paint. The film of acid formed on the interior surfaces softens the paint and causes it to shed. The soluble residues gathering in water and subsequently dripping upon the plants in the beds have been the cause of much plant injury. These effects from the burning of sulfur have been the chief factor in discouraging the practice for cleaning up pests between plantings.

Read and Orchard (35) and Read (36) found that zinc sulfate was formed from the action of sulfuric acid on white zinc paints and galvanized wire, and that 1 pound of sulfur to 1,000 cubic feet resulted in considerable drip damage. No damage resulted where surfaces were protected with lead or barium base paints. More recently Kadow et al. (25) reported an instance of injury to tomatoes from drip from zinc galvanized pipes and wires in a greenhouse where sulfur had been burned as a clean-up measure, but the exact dosage was not stated. In Massachusetts greenhouses injuries to plants from drippings from iron pipes, zinc-coated wires and metal, and from surfaces covered with zinc paints following the burning of large amounts of sulfur have been frequent. A study of the problem, therefore, seemed desirable.

Reaction with Paint

Various paint pigments[3] were added to water and painted on panes of glass. After drying, these pigments were exposed in a large chamber to burning sulfur fumigation and 5 percent suspensions of the residues in distilled water were made. The filtrates were tested for pH values and then sprayed on delphinium and tomato plants for toxicity manifestations. The results were recorded three to five days after spraying (Table 12). Injury of varying degree occurred. The greatest injury resulted from zinc oxide and leaded zinc. Basic lead carbonate and aluminum powder did not cause injury. No definite correlation was shown between the pH value of the extract and its toxicity to plant foliage. Some of the pigments showed a marked hydrolysis after fumigation, expressed in the strongly acid character of the filtrates, i. e. titanium dioxide, Titanox B, Lithopone, and zinc sulfide; and extracts of these pigments caused some injury in one or another of the experiments. Extracts of pigments not exposed to burning sulfur fumigation were not toxic.

TABLE 12.—EFFECT OF EXPOSURE OF PAINT PIGMENTS ON GLASS PANES TO FUMIGATION WITH BURNING SULFUR, AND THE ACTION OF EXTRACTS OF THE RESIDUE ON PLANT FOLIAGE

Paint Pigment	pH of Paint Pigment		Degree of Injury from Extract	
	Before SO_2 Fumigation	After SO_2 Fumigation	Delphinium	Tomato
Basic Lead Carbonate	6.6–6.8	6.4-6.6	None	None
Lead Sulfate	6.2–6.4	6.3–6.4	Slight	Slight
Titanium Dioxide	6.6–6.8	3.0 or less	Slight	None
Titanox B	6.8–7.0	3.0 or less	None	None
(Titanium Dioxide....25%)				
(Barium Sulfate.....75%)				
Zinc Oxide	6.6–6.8	6.4–6.6	Severe	Severe
Leaded Zinc	6.6–6.8	6.4–6.6	Severe	Severe
(Zinc Oxide.....65%)				
(Lead Sulfate.....35%)				
Zinc Sulfide	7.0–7.2	4.4–4.6	None	Slight
Lithopone	7.0–7.2	4.3–4.5	None	Slight
(Zinc Sulfide.....28%)				
(Barium Sulfate.....72%)				
Aluminum Powder		4.6	None	None

These same white pigments were moistened in Petri dishes and exposed to an atmosphere of burning sulfur. They were then dried and washed and the amount of water-soluble material in each determined (Table 13). Basic lead carbonate, which did not cause injury in any of the experiments, showed the least water-soluble material. Zinc oxide and leaded zinc, which caused the greatest injury, also yielded the most water-soluble material. In other instances injury, if any, was slight and the amount of water-soluble material was likewise small in proportion. The zinc oxide pigments Nos. 2 and 412 were rendered appreciably soluble.

[3]Paint pigments supplied through the courtesy of Sherwin-Williams Company, Cleveland, Ohio.

TABLE 13.—AMOUNT OF WATER SOLUBLE SALT RESULTING FROM EXPOSURE OF WHITE PAINT PIGMENTS ON GLASS TO FUMIGATION WITH BURNING SULFUR

Paint Pigment	Stock Number (Sherwin-Williams Company)	Pigment Recovered Grams	Water Soluble Salt Grams	Water Soluble Salt Percent
Basic Lead Carbonate	18	3.63	0.03	0.83
Lead sulfate	9	3.11	0.11	3.54
Titanium Dioxide	1403K	2.65	0.07	2.64
Titanox B	1097	1.78	0.03	1.69
(Titanium Dioxide....25%)				
(Barium Sulfate.....75%)				
Zinc Oxide	2	6.97	2.95	42.32
Leaded Zinc	412	3.82	1.21	31.68
(Zinc Oxide.....65%)				
(Lead Sulfate.....35%)				
Zinc Sulfide	1538	2.56	0.09	3.52
Lithopone	416C	2.42	0.11	4.55
(Zinc Sulfide.....28%)				
(Barium Sulfate.....72%)				

TABLE 14.—EFFECT OF EXPOSURE OF PAINT PIGMENTS IN OIL ON WOOD TO FUMIGATION WITH BURNING SULFUR, AND THE ACTION OF EXTRACTS OF THE RESIDUE ON PLANT FOLIAGE

Paint Pigment	pH of Extract	Degree of Injury from Extract: Lettuce	Degree of Injury from Extract: Tomato
Basic Lead Carbonate (18)	4.2–4.4	None	None
Lead Sulfate (9)	4.8–5.0	Slight	Slight
Titanium Dioxide (1403K)	3.0 or less	Slight	Slight
Titanox B (1097)	3.0 or less	None	Trace
(Titanium Dioxide....25%)			
(Barium Sulfate.....75%)			
Zinc Oxide (2)	6.2–6.4	Severe	Severe
Leaded Zinc (412)	6.2–6.4	Severe	Severe
(Zinc Oxide.....65%)			
(Lead Sulfate.....35%)			
Zinc Sulfide (1538)	3.3–3.5	None	None
Lithopone (461C)	3.3–3.5	Slight	Slight
(Zinc Sulfide.....28%)			
(Barium Sulfate.....72%)			
Powdered Aluminum	4.6	None	None
Aluminum Paint Mixture	4.6–4.8	Slight	None

In a further experiment the various paint pigments were mixed with linseed oil and painted on wood. After drying, the painted boards were exposed in a humid chamber to fumigation with burning sulfur. After fumigation, the paint

coatings were removed and added to water to make a 10 percent extract. The extracts were tested for pH values and atomized on foliage of tomato and lettuce for an index of their toxicity (Table 14). The results confirm the fact that zinc oxide in paint on interior greenhouse surfaces can be a major cause of drip injury following fumigation with burning sulfur.

TABLE 15.—AMOUNT OF WATER SOLUBLE ZINC IN RESIDUES RESULTING FROM EXPOSURE OF ZINC WHITE PAINTS TO FUMIGATION WITH BURNING SULFUR AND THE ACTION OF EXTRACTS OF THE RESIDUES ON LETTUCE AND TOMATO FOLIAGE

Composition of Paint*		Degree of Injury from Extract		Water Soluble Zinc in 5 cc. of Extract	
		Lettuce	Tomato	Zinc Grams	Zinc as Zinc Sulfate Grams
Zinc Oxide and Asbestine					
25%	75%	Trace	Severe	0.0528	0.2322
50%	50%	Moderate	Severe	.0643	.2827
75%	25%	Severe	Severe	.0572	.2515
Leaded Zinc and Asbestine					
25%	75%	None	Severe	.0314	.1381
50%	50%	Slight	Severe	.0478	.2102
75%	25%	Severe	Severe	.0460	.2023
Zinc Oxide and Basic Lead Carbonate					
25%	75%	Slight	Severe	.0298	.1310
50%	50%	Severe	Severe	.0338	.1486
70%	30%	Slight	Severe	.0387	.1702
90%	10%	Slight	Slight	.0125†	.0549
Zinc Oxide and Titanium Dioxide					
25%	75%	Severe	Severe	.0541	.2379
50%	50%	Severe	Severe	.0727	.3197
70%	30%	Slight	Severe	.0494	.2172
90%	10%	Slight	Severe	.0316	.1389

*Asbestine=Magnesium silicate, calcium carbonate not more than 4%.
Leaded Zinc=Zinc oxide 65%, lead sulfate 35%.
†1 cc. sample.

A further comparative test was made of several prepared paints[4] containing different ratios of zinc oxide. The paints were applied to panels of wood, allowed to air dry, and then exposed to fumigation of burning sulfur in a glass chamber. The residues were removed and treated with distilled water to make a 50 percent mixture. All of the extracts were toxic to tomato foliage (Table 15). Quantitative analysis of 5 c. c. samples of the extracts yielded zinc, and the paint residue yielding the smallest amount of zinc sulfate caused the least injury. None of the extracts contained more than a trace of sulfides or sulfites, from which it may be inferred that sulfurous acid is not involved in the problem of injury. The injury to tomatoes in commercial houses proceeds gradually and continuously for a long time and often extends into the second and later plantings after fumigation. This

[4]Paints were supplied by the Sherwin-Williams Company, Chicago, Illinois, and by the Norfolk Paint and Varnish Company, North Quincy, Massachusetts.

suggests a gradual release of the soluble toxic salt into the drip. A 1 percent solution of chemically pure zinc sulfate is very injurious to tomato foliage, and Read and Orchard (35) found that a 0.3 percent solution is the maximum concentration tolerated by chrysanthemum plants without noticeable injury.

In a final experiment six proprietary white paints selected to contain different amounts of zinc oxide and varying otherwise in their composition were painted on wooden panels. The same procedure of fumigation and collection of the fumigated residue was followed, and 10 grams of dry residue were added to 40 c. c. of distilled water. The extracts were tested for sulfides and sulfites and analyzed for sulfates and zinc. Small samples of the extracts were atomized on tomato foliage in the greenhouse. The degree of injury was recorded 3 days after the treatment (Table 16).

The analyses confirm the results of the previous experiment. Soluble sulfides and sulfites were lacking or never more than a trace. The amount of zinc recovered from the extracts and the degree of injury to the test plants were in rather definite proportion to the amount of zinc oxide pigment in the paint. The Lucas paint, which contains 5 percent zinc oxide, yielded after fumigation the smallest amount of sulfates and zinc and caused no injury. The DuPont, Lowe Bros., and Kyanize paints, containing 27, 25, and 33 percent zinc oxide pigment respectively, yielded the largest amounts of soluble sulfates and zinc salts and caused the most injury to tomato foliage.

The Lucas and particularly the white lead paint residues on the wooden surfaces were dry and firm upon the removal of the panels from the humid sulfured chamber. The other paint residues were soft and greasy. The problem of compounding a paint for interior greenhouse use that will not be softened and shed by the action of sulfuric acid from the burning of sulfur is beyond the scope of this study, but its significance is to be noted as a matter of record. There is some suggestion of the value of the carbonates of lead and calcium in the composition of the paint as a deterrent to this condition.

Judging from the results reported in Table 16, a small amount of zinc oxide in the composition of paint, e. g., as much as 5 percent, may be tolerated. However, it would seem safer to exclude zinc oxide altogether from interior greenhouse painting. Read and Orchard (35) stated that the burning of sulfur is not advised except when the interior painting is free from zinc. The former precaution seems preferable, since sooner or later the occasion may arise for burning sulfur between crops as a sanitary pest control measure. Undoubtedly, the amount of plant poison dissolved in the drip is increased slightly by the fact that all zinc pigments in white paints contain a trace to small amounts of zinc sulfate (51).

Reaction with Metal Surfaces and Trellis Wire

Aside from the plant injury from metallic salts dissolved in the drip water after fumigation with burning sulfur, the greenhouse interior metal construction is corroded and the usefulness of the trellis wire is greatly reduced. On galvanized metal surfaces the chemical salt formed during the fumigation period has the properties of white vitriol (zinc sulfate). Sulfur dioxide from burning sulfur is converted quickly into sulfurous and sulfuric acids as is suggested by the thick deposit of the white crystalline salt on galvanized metal surfaces at the end of the fumigating period. Kadow et al. (25) mention the formation of a greenish yellow salt of possibly zinc thiosulfate and the probability of its oxidation to zinc sulfate.

In the case of injury on tomatoes which came to the writer's attention in the spring of 1937, all of the damage was confined to plants directly below rusted iron pipes and span supports. In this instance an excessively large dosage of sulfur was burned previous to the removal of the preceding planting of tomatoes. Such

a condition could be avoided by painting the iron with white lead or zinc-free paint. The same protection from the formation of chemical residues harmful to plants can be obtained by painting the metal gutters, posts and other overhead metal construction.

TABLE 16.—ANALYSES OF RESIDUES OF PROPRIETARY WHITE PAINTS EXPOSED TO FUMIGATION WITH BURNING SULFUR, AND ACTION OF EXTRACTS ON TOMATO FOLIAGE

Paints	Zinc Oxide Percent	Sulfides	Sulfites	Sulfates (SO_3) Percent	Zinc Percent	Suspension	Degree of Injury to Tomato
DuPont[1]	27	None	Trace	4.90	5.72	Fair	Severe
Lowe Bros.[2]	25	None	Trace	4.80	5.62	Fair	Severe
Lucas[3]	5	None	None	0.78	0.64	Poor	None
White Lead	0	None	None	None	None	Poor	None
Norfolk[4]	15	Very slight trace	Trace	3.62	4.36	Fair	Slight
Kyanize[5]	33.3	None	Trace	4.60	5.38	Fair	Severe

[1]DuPont Prepared Paint 40. Outside White
Pigment 65%; Vehicle 35%
White Lead.....30%
(Basic carbonate white lead 52%; basic sulfate white lead 48%)
Titanium Barium Pigment.....38%
Zinc Oxide.....27%
Silicates..... 5%

[2]Lowe Bros. High Standard House Paint. White 328
Pigment 65%; Vehicle 35%
Basic Carbonate White Lead.....37%
Basic Sulfate White Lead.....13%
Zinc Oxide.....25%
Titanium Dioxide.....12.5%
Magnesium Silicate.....12.5%

[3]John Lucas & Co. Lucas Tinted Gloss Paint. Inside White
Zinc Oxide..... 5%
Titanium Pigment.....35%
Calcium Carbonate..... 7%
Linseed Oil.....14%
Varnish.....33%
Drier..... 1%
Volatile Thinner..... 5%

[4]Norfolk Paint & Varnish Co. T. L. Z. Paste White
Lead Sulfate.....15%
Titanox A..... 6% (Titanium dioxide)
Zinc Oxide.....15%
Titanox B.....30% (Barium sulfate 70%; Titanium dioxide 30%)
Asbestine.....20%
Lead Titanate.....14%

[5]Boston Varnish Co. Kyanize 600. Outside White
Pigment 62%; Vehicle 38%
Carbonate of Lead.....33.3%
Zinc Oxide.....33.3%
Titanox.....33.4%

Because trellis wires cannot be easily or satisfactorily painted, the matter of an inert wire offered a further problem of study. Different kinds of wire were obtained for experimental tests. After exposure to burning sulfur fumigation in a moist atmosphere, the wires were scraped to remove the chemical residue produced from the reaction, and 5 percent suspensions in distilled water were made. The filtrates were applied to lettuce and tomato leaves with an atomizer and the results noted (Table 17).

TABLE 17.—ACTION OF BURNING SULFUR FUMIGATION ON WIRE AND TOXICITY OF EXTRACT OF THE RESULTING RESIDUE TO PLANT FOLIAGE

Type of Wire	Residue	Degree of Injury from Extract		Price[3] per Cwt. No. 16 Wire
		Lettuce	Tomato	
Stainless Steel[1]	None	None	None	$76.75
Bethanized Steel[1]	Thick white	Severe	Severe	7.045
Tinned Steel[1]	Moderately rusted	None	None	6.345
Zinc Galvanized Iron	Thick white	Severe	Severe	5.995
Black Enameled Copper[2]	None	None	None	10.000
Uncoated Steel Wire				6.75

[1]Furnished through the courtesy of Bethlehem Steel Company, Bethlehem, Pennsylvania.
[2]Furnished through the courtesy of Essex Wire Corporation, Detroit, Michigan.
[3]Prices are of December 1, 1936, by Philip A. Rand, Boston, Massachusetts.

Stainless steel wire is steel throughout with some alloys. Bethanized steel wire is a special zinc galvanized steel wire. Tinned steel wire is coated with tin. Black enameled copper wire is coated with a black enamel. These wires were compared with zinc galvanized iron wire, the common grade of wire used in the greenhouse for supporting trellised plants. The 5 percent extracts of the residues from the zinc-coated wires were very injurious to lettuce and tomato foliage, but extracts of residues from tinned, enameled, and stainless steel wires were not. The use of zinc galvanized wires in greenhouses where sulfur is burned invites serious drip injury to the succeeding planting. The injurious substance formed is zinc sulfate and the amount of damage is obviously influenced by the amount of sulfur burned and moisture conditions. Tinned steel wire, which compares favorably in price with galvanized iron wire, reacted with the sulfur gas, judging from the presence of a moderate amount of rust-colored residue, probably iron sulfate; but a 5 percent extract of it was not injurious to lettuce and tomato foliage.

In a further experiment the percentage of water-soluble material formed by the reaction and the character of the soluble residue were determined. Water extracts of these residues (5 and 2½ percent strength) were atomized on tomato foliage for toxicity values (Table 18). The percentage of soluble material in the residues was most pronounced with Bethanized zinc galvanized wire. The severity of injury was definitely correlated with zinc sulfate. The 5 percent extracts of the residues from tinned and uncoated steel wires were only slightly injurious and the action of a 2½ percent extract was negligible. Therefore, uncoated or tin-coated steel wire would be preferable to zinc galvanized wire in greenhouses so far as compatibility with burning sulfur fumigation is concerned. The cost of the stainless steel wire, which did not react, is, however, prohibitive.

TABLE 18.—ANALYSIS OF RESIDUES ON WIRES AND ACTION OF WATER SOLUBLE EXTRACTS ON TOMATO PLANTS

Type of Steel Wire	Character of Residue	Qualitative Test for						Soluble Material	Degree of Injury to Tomato Foliage	
		Fe	Cr	Sn	Ni	Zn	SO_4	Percent	2.5 percent Extract	5 percent Extract
Stainless	White powdery "bloom"	Tr	Tr		—		—	28.8	None	None
Bethanized	Thick white	—				+	+	98.2	Severe	Severe
Tin Coated	Thick dark brown	+		—			+	66.3	Trace	Slight
Uncoated	Thick pale brown	+					+	76.6	Trace	Slight

Other Considerations

The rate of burning sulfur has a definite bearing upon the extent of the reaction with metal and zinc paint. In the writer's experiments, dosages ranging from 1 ounce to 1 pound of sulfur in a gas-tight greenhouse of 1,500 cubic feet, when the gas was confined for 24 hours, were lethal to the fungus. Under greenhouse conditions, 4 pounds to 10,000 cubic feet, divided into two heaps, was lethal to tomato plants and spores of tomato leaf mold, white fly, and aphis. Drip injury to succeeding plantings was reduced to small relative or negligible importance in several large greenhouses where sulfur was burned at this rate, and the growers expressed satisfaction with the destructive effect of the treatment upon plant life and the common insects.

While the reaction occurs at small ratio treatments, it becomes even less significant or negligible if dry conditions are obtained for the fumigating period. In view of the extensive amount of vine and foliage and the moist condition of the soil, high relative humidity and water of condensation are often difficult to avoid. The precaution of allowing the beds to dry off at the end and the use of pipe heat should produce the dry greenhouse conditions necessary to render fumigation safe.

As a further precaution against drip injury, the poisonous residues on metal and paint can be more or less completely removed by thoroughly hosing down the greenhouse interior with water or with a 5 percent solution of sal soda. The influence of the soda solution on the resulting reaction of the soil suggests a further problem. Since the burning of sulfur at the rate of 4 pounds to 10,000 cubic feet under dry conditions has not produced drip injury of any consequence in various trials observed, there would not seem to be any need for washing down the greenhouse interior after the fumigating period.

Formaldehyde Fumigation

In view of the corrosive action of sulfur dioxide on metal, wires, and painted surfaces in the greenhouse, and the danger of damage to the succeeding crop from the metal and paint drippings, it might appear desirable under some conditions to rely on other materials to eradicate infestations of red spider mite. European reports recommend thoroughly washing down the interior and exterior of the greenhouse with cresylic acid emulsion, phenol solution, or formaldehyde (1,20,36) to kill mites and fungous spores. The greenhouse is tightly closed for about four days to maintain a killing atmosphere and then cleared out. Judging from one

report the washes are the more modern method of disinfestation; but according to a more recent report the treatment is apparently no more efficient than sulfur dioxide in destroying the mites in crevices and cracks. Under our conditions the disinfestation of the vines and interior with a wash before clearing out would be difficult and impractical and is not justified in view of the efficiency of such fumigants as naphthalene and hydrocyanic acid gas which, unlike sulfur, are inert to metal and paint even at high dosages. Both eggs and mites succumb to these treatments.

Both naphthalene and hydrocyanic acid gas, even when generated in large excess, are inert to the spores of the tomato leaf mold fungus. In two separate experiments in a tight greenhouse of 1,500 cubic feet, Cladosporium spores were exposed to 8 ounces of vaporized naphthalene for 72 hours at a temperature of 70° to 80° F. and to 16 ounces for 4 days at a temperature of 80° to 86° F. In the latter case there was a heavy deposit of naphthalene on the glass, but this had all disappeared at the end of the 4-day period. There was no lethal effect on the spores. In the same volume of atmosphere, hydrocyanic acid gas was generated from sodium cyanide (10.6 grams), sulfuric acid (16.5 c. c.), and water (22.5 c. c.) and confined for 48 hours. In multiples of this dosage up to 15 times, not the least effect was shown on the viability of the spores of *Cladosporium fulvum* Cke. and *Botrytis cinerea* Pers. These results are in line with the generally accepted view that naphthalene and hydrocyanic acid gas lack fungicidal value. When either of these insecticides is used, it would seem desirable to fumigate further with a fungicide to complete the disinfestation of the greenhouse interior. The burning of sulfur in small dosages, not in excess of 4 pounds per 10,000 cubic feet, is lethal to fungous spores and most insects, and is justified in view of its negligible cost and practical use. Where a definite prejudice against sulfur exists, formaldehyde fumigation may be substituted.

The findings and opinions as to dosages of formaldehyde gas lethal to the spores of the tomato leaf mold fungus are quite inconsistent as may be noted from a study of Table 19. In addition, Williams (54) noted that the fungus in culture was killed on exposure to formaldehyde vapors for one hour and that spores exposed for 8 hours were killed, but the concentration of the gas was not stated.

TABLE 19.—CONCENTRATIONS OF FORMALDEHYDE REPORTED TO BE TOXIC TO SPORES OF *Cladosporium fulvum* CKE.

(Amounts per 1,000 cubic feet.)

Authority	Formaldehyde Fluid Ounces	Permanganate of Potash Ounces	Period	Remarks
Makemson (26).....	48	23	24 hours	Not lethal
Small (44, 46).....	3.2	2	Not stated	Almost completely lethal
Parker (33).....	5		24 hours	Good results
Van der Meer (52) ..	1	½	Not stated	Minimum toxic dose in laboratory

Some tests were conducted in a gas-tight greenhouse of 1,500 cubic feet. Tomato leaves bearing the fungus were exposed for 24 hours. The reacting chemicals were used in increasing amounts from 2 to 10 fluid ounces of formaldehyde with 1.6 to 8.3 ounces of permanganate of potash. All dosages were lethal to the spores of the fungus. In a greenhouse of 10,000 cubic feet, ratios as low as 24 fluid ounces of formaldehyde and 20 ounces of permanganate of potash, with ventilators closed for 24 hours, killed both spores and plants. This appeared to be the minimum lethal dosage under greenhouse conditions, since ratios of 20 fluid ounces of formaldehyde and 17 ounces of permanganate of potash to 10,000 cubic feet, and lower ratios, were not generally toxic to the fungus. In a greenhouse of 31,000 cubic feet, 96 fluid ounces of formaldehyde and 80 ounces of potassium permanganate, which is stronger than the 24-20-10,000 ratio, were lethal to Cladosporium spores and tomato plants but not to the greenhouse white fly. For houses that leak more or less, a ratio slightly higher than the recommended dosage is desirable.

In fumigating with formaldehyde gas, vessels of rather large volume are necessary to guard against overflow of the foaming liquid during the reaction. A 5-gallon vessel about 8 inches in diameter for each 10,000 cubic feet is suggested. The vessels should be narrow enough so that the crystals of potassium permanganate are covered by the formaldehyde. The required amount of liquid is placed in each container. The required amount of potassium permanganate is weighed out in paper sacks and set beside each container. These are added to the vessels, beginning with the one farthest from the exit. A quiet atmosphere is desirable for an effective fumigation and the greenhouse should be closed tight for 24 hours.

The cost of fumigating 10,000 cubic feet of greenhouse with formaldehyde at the suggested ratio is about 53 cents as compared to 16 cents for sulfur on the basis of 4 pounds to 10,000 cubic feet. In view of the large difference in cost and the lack of insecticidal effect from formaldehyde, the burning of sulfur in small amounts for fungicidal purposes seems preferable. For a more complete kill of the red spider mite, a supplementary fumigation with either naphthalene or hydrocyanic acid gas is recommended. Formaldehyde, naphthalene, and hydrocyanic acid gas are inert to paint and metal but lack the merit of a satisfactory disinfestant in being only either fungicidal or insecticidal.

Chemical Soil Sterilization

Formaldehyde when used as a soil sterilizing agent produces a greenhouse atmosphere lethal to fungous spores. Carbon disulfide emulsion when used on the soil to kill soil-infesting nematodes produces an atmosphere that is lethal to most insects. The application of both chemicals in combination to eradicate soil-inhabiting fungi and nematodes produces a strongly lethal greenhouse atmosphere. To obtain a thorough fumigation, the concentration of these gases should be maintained for two to three days by keeping the ventilators tightly closed.[5] Since soil-sterilizing chemicals are applied after the plants are cleaned out, the fumigation of the interior resulting from chemical soil applications does not do what is accomplished by the disinfestation of the old infested vines.

[5]The use of these chemicals for sterilizing greenhouse soil is described in Mass. Agr. Expt. Sta. Bul. 292, "Carbon Disulfide Emulsion for the Control of the Root-Knot Nematode."

SUMMARY

In Massachusetts, tomato leaf mold, due to the fungus *Cladosporium fulvum* Cke., is of importance only in greenhouse culture. Its occurrence is associated with the off-heating or warmest season of the year when the mean maximum relative humidity and temperature are highest and when the difference between the inside and outside mean minimum temperature is least.

The successful control of the disease involves cultural practices, greenhouse management, greenhouse location and design, and the use of chemicals for the disinfestation of the greenhouse interior and the protection of the plants from infection.

Light and free circulation of air contribute to the control of the disease. These conditions are promoted by the proper spacing of the plants and pruning.

Careful bottom-watering makes for dry foliage and is an aid to the control of the disease. Overhead watering or watering with the open hose should be avoided. Watering should be done in the morning and on bright days to insure, so far as possible, dry conditions at night.

Ventilation to prevent abnormal atmospheres such as high temperatures, stagnant air, and high relative humidity is intimately bound up with the problem of control. The need for adequate ventilating area on all sides and both spans of the greenhouse is imperative in tomato culture to permit the closest approach to normal or outside atmospheres during the off-heating or critical season.

Heat employed intelligently with ventilation late in the spring and early in the fall season of growing can delay the progress of disease, or through careless use may readily encourage an epidemic.

Heat and ventilation to maintain inside minimum temperatures of 60° to 65° F. as the outside temperatures drop to 50° late in the spring and early in the fall, and full ventilation at other times during the milder critical months would appear to be the most economical method of control. During the heating months, periods occur when the outside temperatures converge closely upon the inside minimum growing temperature of 60° F. and render control of the relative humidity difficult. Otherwise the wide difference in temperature and the resultant influence on the relative humidity explain the absence or slow development of the disease in the colder months of the year. Condensation of moisture from the air as dew and guttation from the plant itself contribute to the progress of the disease and can be prevented by cultural and greenhouse management practices.

Good management in contrast to poor management controlled the disease rather well in some seasons, but in others was less effective.

Several automatic or mechanical systems of air conditioning are described. Controlled relative humidity below 85 percent within a temperature fluctuation of 60° to 75° in conjunction with forced air was contrasted with a minimum fixed temperature of 60° F. and hand ventilation. Better disease control under the automatic humidity control was not accompanied by better yields, and the installations were too expensive to warrant commercial use. A constant minimum temperature control has many advantages over hand control and is worthy of installation in commercial practice.

Control of the disease is intimately bound up with greenhouse location and design. Location with regard to good air circulation is an important aid to successful management.

The vaporization of sulfur at regular and close intervals beginning in April in the spring growing season and before planting in the fall season is an efficient contributory method of control. The sulfuring of the heating pipes is not a comparable method of vaporizing sulfur and may encourage rapid progress of the disease.

Because of unsatisfactory protection of the lower surfaces of tomato leaves, and conditions peculiar to greenhouse culture, the use of fungicidal sprays and dusts is not effective.

The disinfestation of the greenhouse interior with chemical fumigants is a desirable sanitary measure and should be done just before the finished planting is cleaned out. Burning sulfur and formaldehyde have received the widest recognition for fumigation. The burning of sulfur is customary because it is economical, practical, and lethal to both fungi and insects.

The usual recommended rate of application of 1 pound of sulfur to 1,000 cubic feet is excessive and invites dangerous chemical reactions with galvanized metal surfaces, iron pipes, and paints containing zinc. The resulting soluble residues in the drip water injure the succeeding plantings. The burning of 4 pounds of sulfur to 10,000 cubic feet under relatively dry conditions is safe. This application is lethal to tomato leaf mold spores, plant life, and the common insects except the red spider mite. Hydrocyanic acid gas and naphthalene vapors are inert to metal and paint and in strong enough dosages are lethal to red spider mites and eggs but have no fungicidal value. Either should supplement the sulfur treatment to obtain a more complete disinfestation of the greenhouse interior. Paints containing zinc should not be used in interior greenhouse painting, and metal surfaces should be protected with white lead or paints free of zinc. Where sulfur is customarily burned, tinned or uncoated steel trellis wires should be used instead of zinc galvanized iron wires. Dry greenhouse conditions during the sulfur fumigation period should prevail.

Formaldehyde vapors have a lethal action only on fungi and are inert to metal and paint. Under commercial greenhouse conditions a dosage of 24 fluid ounces of formaldehyde and 20 ounces of potassium permanganate to 10,000 cubic feet is lethal to plants and to tomato leaf mold spores. Cost of the materials in these proportions is about 53 cents as compared with 16 cents for sulfur at the rate of 4 pounds to 10,000 cubic feet.

The dual value of sulfur, its practical utility, and its economy lead to its endorsement in practice.

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